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APPLICATION OF GREY RELATIONAL ANALYSIS FOR MULTI RESPONSE OPTIMIZATION OF PROCESS PARAMETERS IN DRILLING OF CARBON-BASALT HYBRID COMPOSITE

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ABSTRACT

The present work deals with a simple approach which predicts the optimum setting of process parameters of drilling operation on Carbon Basalt hybrid composite. The process parameters selected are Drill diameter (DD), Speed (N) and Feed (f). The output parameters are Thrust, Torque, Surface Roughness and Delamination. Three levels of each input parameters are considered. Taguchi's L27 array is used to set the process parameters. Gray relational analysis (GRA) is used to find the optimum value of process parameters. Conduction of ANOVA on GRA shown the significance of each factor on the process output. A confirmation test conducted revealed that the setting of parameters ensures optimum output.

KEYWORDS: Drilling, PBGF Composite, Orthogonal Array & Gray Relational Analysis

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Original Article

1. INTRODUCTION

Basalt is the very common rock which is found in earth crust. Russia has unlimited basalt reserves and only the 30 active quarries have roughly 197 million m^3 [1]. By melting basalt rock at 1300–17000 degree Centigrade and spinning it [2, 3] Basalt fibers are produced. Due to the problems in fiber production problems such as gradual crystallization of some parts and nonhomogeneous melting, continuous basalt fibers were rarely used until the technology of continuous spinning was developed in recent years [4]. The weight percentage of the constituent oxides present in basalt rocks: SiO_2, 48.8-51; Al_2O_3, 14-15.6; CaO, ≈10; MgO, 6.2- 16; FeO + Fe_2O_3, 7.3-13.3; TiO_2, 0.9-1.6; MnO, 0.1-0.16; Na_2O + K_2O, 1.9-2.21 [1]. Basalt shows 5% higher density than the glass. Most of the earlier references claimed that, compared to glass, basalt fiber have possesses better mechanical properties [5, 6]. Compared to glass fibers, basalt fibers shows wider range of operating temperature and higher application temperature. The cost of basalt fiber is higher than the glass fiber but cheaper than the carbon fiber which is known for better performance. Since the cost of the basalt is cheaper than carbon fiber and performance is quite appreciable, basalt-carbon fibers are blended together to reduce the cost and to enhance the properties of the composite produced.

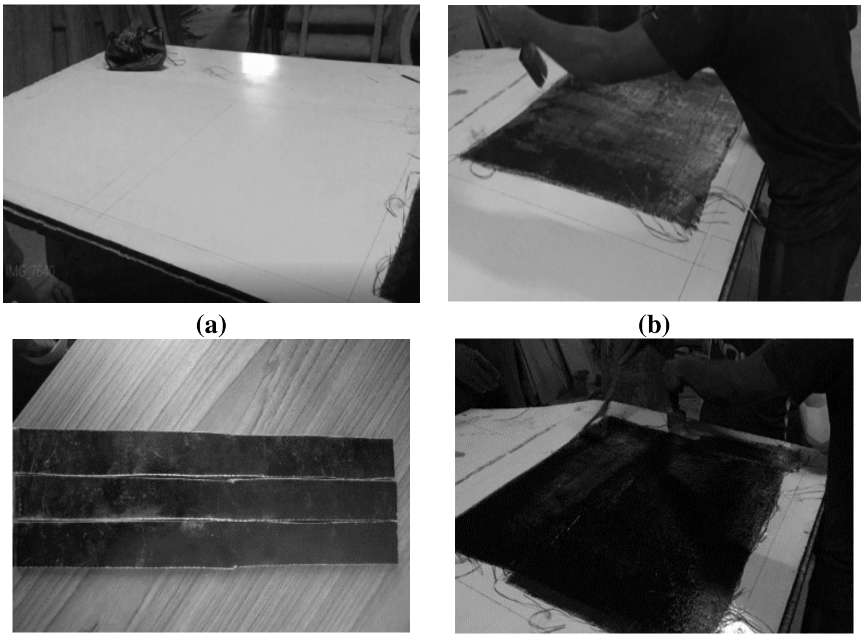
Drilling is an inevitable process in any fabrication. Drilling of holes are required for assembly purpose. Drilling of composites poses problems like rough internal surface, delamination, sudden variation in thrust etc. Good quality holes are very essential in order to achieve leak proof joints. Previous investigation works have proven that the quality of the hole obtained is dependent on many process parameters such as drill diameter, feed rate, drill point angle, drill speed

etc.[7-13]. Hence many researchers have worked in this direction to minimize the damage by having control over the input and process parameters. Optimization of the process parameters is one of the methods to reduce the damage during drilling and to get acceptable quality of product. Many researchers have used various optimization techniques such as Taguchi Method, Response surface Methodology, Genetic Algorithms, System Dynamics etc., Amruthakannan et al did the assessment of delamination during drilling of basalt fiber reinforced composite through the Taguchi optimization technique [14]. C.C. Tsao et al., used to Taguchi and Neural Network methods to optimize the process parameters to obtain the better surface quality in drilling of Composite materials [15]. Rodrigues et al., optimized the process parameters through Response Surface Methodology is to minimize the surface roughness in the drilling of GFRP composites [16]. All these methods mentioned above are single parameter optimization technique, either minimizing delamination or minimizing surface roughness etc. The method proposed in this paper aims at multiple parameter optimization taking all the output parameters into account simultaneously.

2. EXPERIMENTAL METHOD

2.1 Fabrication of Specimen

Preparation of test specimen: Hand-lay-up method was used to prepare the specimen of composites. A defect free and homogenous hybrid composite specimen is prepared in a polymer industry under the supervision of an expert. In the beginning, a mold has been made to the required dimensions. In general, the mold is white color wooden table. Next the mold is properly cleaned and washed using wax, as it helps to reduce the sticking of the fiber to the mold. Later on, wax is applied and once it is dried, a measured quantity of resin is applied over the mold. Further, the first layer of the basalt is compressed on the mold by using a roller and also the resin is applied over the carbon fiber which is the second layer of fiber. Using the roller trapped air is removed from the composite. Next the addition process of the third layer of fiber and resin is done. Like this staking of alternate layers of carbon and basalt mat will be continued until obtain the required thickness. The figure 1(A, B, C, D) shows the stages of preparation of test specimen. A weight ratio of 1:1 was used in this process between the fiber and resin to prepare the hybrid composite. The thickness of the composite developed is 6 mm. The properties of the basalt and carbon fibers used to prepare the hybrid composite specimen is presented in Table 1



(a) (b) (c) (d)

Figure 1: Stages of Specimen Preparation.

Table 1: Properties of Carbon and Basalt Fibers

		Carbon	Basalt
Fiber species	Warp	3k	300
	Weft	3k	300
Woven Pattern		**Plain**	**Plain**
Linear Density (10mm)	Warp	5	5
	Weft	5	5
Thickness (mm)		**0.3**	**0.32**
Area Weight (g/m2)		200	320
Tensile Strength (Mpa)		3520	3000
Modulus in Tension (Gpa)		230	90
Elongation (%)		1.5	3.3

2.2 Selection of Levels of Drilling Parameters

The input drilling parameters are selected as per the available literature survey information. High speed steel drill bits are used for drilling the holes. The parameters and their levels chosen for the present work are shown in Table 2.

Table 2: Levels of Process Parameters

Parameters	Drill Diameter (DD) mm (A)	Speed (N) RPM (B)	Feed (f) m/min (C)
Level 1	6	750	50
Level 2	8	1000	75
Level 3	10	1250	100

2.3 Measurement of Response

The process parameters are selected according to Taguchi's L27 orthogonal array. This array ensures minimum number of experiments to be conducted with nearly accurate solution. The drilling experiments were conducted on a CNC machine which is capable of drilling holes accurately and precisely. The experimentation set up to drill the holes and to measure the thrust and torque produced during the machining process is shown in figure 2. The thrust force and torque are measured using Kistler dynamometer, surface roughness using Taylor Hobson Surtronic 3+ roughness measurement instrument and delamination factor was estimated by taking the images of the drilled holes with the help of high resolution scanner and measuring the dimensions of scanned images by using CATIA software. Arrangement made to measure the surface roughness and the delamination is illustrated in figures 3 and 4. All measured output values are illustrated in table 3.

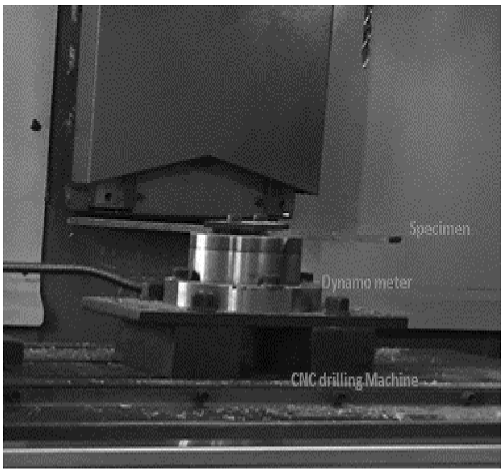


Figure 2: Experimental Set-up to Conduct the Drilling Process.

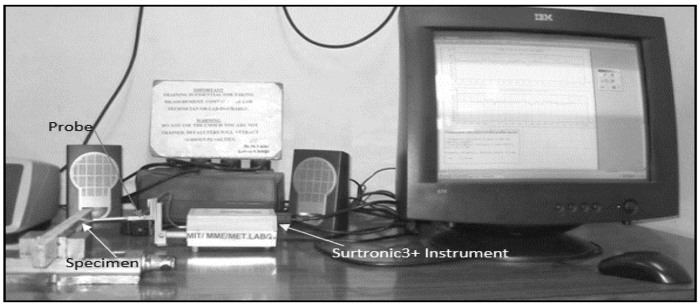


Figure 3: Measurement of Surface Roughness

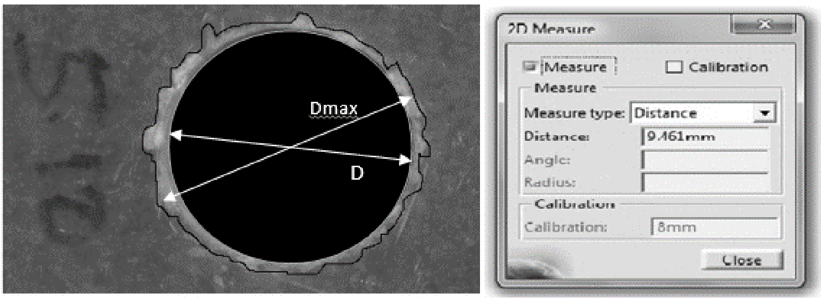


Figure 4: Measurement of Delamination Factor

Table 3: L_{27} Orthogonal Array with Factors and Responses

Trial No	A	B	C	Thrust (N)	Torque (N-mm)	Delamination	Surface Roughness µm
1	1	1	1	62	0.0596	1.0475	6.03
2	1	1	2	99.9	0.1157	1.065	9.56
3	1	1	3	127	0.1461	1.135	11.29
4	1	2	1	53	0.0457	1.066	8.47
5	1	2	2	83.72	0.0885	1.084	9.48
6	1	2	3	113.9	0.1186	1.158	10.57
7	1	3	1	46.01	0.0384	1.18	12.15
8	1	3	2	74.6	0.0656	1.19	13.8852
9	1	3	3	103.6	0.1016	1.253	14.65
10	2	1	1	78.675	0.0686	1.179	7.15
11	2	1	2	108.8	0.1409	1.186	10.51
12	2	1	3	150	0.2374	1.194	11.52
13	2	2	1	73.815	0.0613	1.182	11.56
14	2	2	2	96.41	0.1360	1.191	12.93
15	2	2	3	131.7	0.1898	1.199	13.59
16	2	3	1	60.923	0.0643	1.189	12.43
17	2	3	2	88.04	0.1206	1.12	14.39
18	2	3	3	124	0.1676	1.233	15.72
19	3	1	1	118.108	0.1478	1.238	8.84
20	3	1	2	157.9	0.2966	1.293	12.43
21	3	1	3	191.799	0.3414	1.363	13
22	3	2	1	107.496	0.1477	1.253	12.06
23	3	2	2	138.9	0.2609	1.35	13.15
24	3	2	3	183.256	0.3450	1.383	13.61
25	3	3	1	101.552	0.1458	1.263	14.5
26	3	3	2	131.8	0.2426	1.368	14.6
27	3	3	3	172.259	0.3074	1.401	15.53

Number of replication of each factor is 1 (k = 1). The responses are measured in different units and has different ranges. In order to compare the combined influence of all the parameters on the multiple outputs which have different ranges and units of measurement is done by normalizing the values. By normalizing each output variable is brought in the range 0 to 1.

3. CALCULATION

3.1 Normalisation of Response

The response parameter are of two types. i.e, beneficiary (maximum the better) and non-beneficiary (minimum the better). For beneficiary attribute j, the normalized parameter of the trial i and replication k is given by $X'_{ijk} = \frac{X_{ijk} - Min\ X_{ijk}}{MaxX_{ijk} - MinX_{ijk}}$ and for non beneficiary attribute $X'_{ijk} = \frac{Max\ X_{ijk} - X_{ijk}}{MaxX_{ijk} - MinX_{ijk}}$ where k is the replication. In this paper all response parameters are non beneficiary type. The actual response X_{ijk} is modified to X'_{ijk} which ranges from 0 to 1. The maximum value of normalized response, irrespective of response parameter is taken as reference value R.

R = $MaxX'_{ijk} = 1$.

3.2 Calculation of Difference Value Δ_{ijk}

The difference value is calculated by, $\Delta_{ijk} = |X'_{ijk} - \mathrm{R}|$. The difference valuesarrange the output response in the ascending order for non-beneficiary attribute. These value is used to calculate Gray relational Coefficient GRC_{ijk}.

3.3 Calculation of Grey Relational Coefficient GRC_{ijk}

The Grey Relational Coefficient is calculated by the formula, $GRC_{ijk} = \frac{Min\Delta_{ijk} + \xi Max\Delta_{ijk}}{\Delta_{ijk} + \xi Max\Delta_{ijk}}$ where ξ is the distinguishing coefficient ranging from 0 to 1. Generally, ξ is taken as 0.5.

3.4 Calculation of Grey Relational Grade GRG_i

The average of GRC in each row is known as Grey Relational Grade GRG_i. The Grey relational grade GRG_i is given by the formula, $GRC_i = \frac{\sum_1^m \sum_1^n GRC_{ijk}}{mn}$ where m is the number of response parameters and n is the number of replications (n = 1).

The calculated GRG is shown in table 4.

Table 4: L_{27} Orthogonal Array with Gray Relational Grades

Trial No	A	B	C	GRG
1	1	1	1	0.9246912
2	1	1	2	0.6820382
3	1	1	3	0.5523481
4	1	2	1	0.8593843
5	1	2	2	0.7064543
6	1	2	3	0.5764679
7	1	3	1	0.7533511
8	1	3	2	0.6257155
9	1	3	3	0.5222359
10	2	1	1	0.7279031
11	2	1	2	0.5541922
12	2	1	3	0.4657071
13	2	2	1	0.6572555

Table 4: Contd.,

14	2	2	2	0.5416629
15	2	2	3	0.4729512
16	2	3	1	0.6679438
17	2	3	2	0.5903177
18	2	3	3	0.4617564
19	3	1	1	0.5501254
20	3	1	2	0.4041181
21	3	1	3	0.3596085
22	3	2	1	0.5085343
23	3	2	2	0.4053401
24	3	2	3	0.353801
25	3	3	1	0.4925165
26	3	3	2	0.4011991
27	3	3	3	0.3500335

4 RESULTS AND DISCUSSIONS

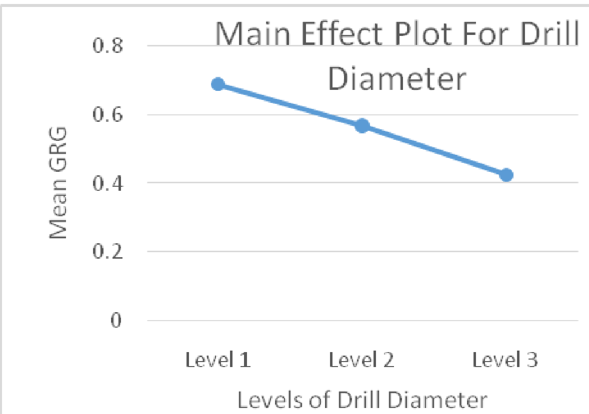
4.1 Calculation of Average GRG for Each Level

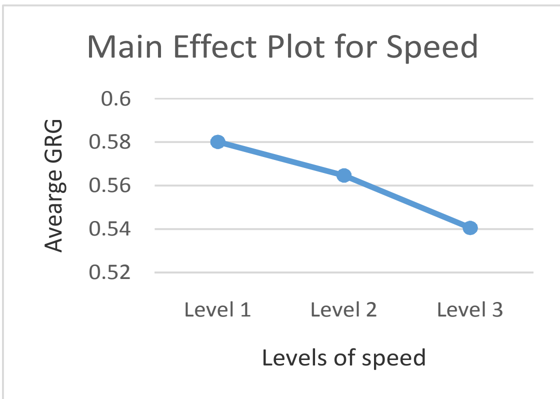
The average GRG is calculated for each level. The Level for which the GRG is maximum for each factor j is the optimal setting of that parameter. The average GRG is listed in table 5. The plot of average GRG Vs Levels of each parameter is shown in figure 5. The level with maximum GRG for any factor is the optimum level for that factor.

Table 5: The Average GRG with Corresponding Factors

Factors	A	B	C
Level 1	0.689187399	0.580081316	0.682411673
Level 2	0.56898152	0.564650168	0.545670918
Level 3	0.425030712	0.540563273	0.457212167
Range	0.264156687	0.039518043	0.225199506
Rank	1	3	2

The range for each parameter is the difference between the maximum average GRG and the minimum GRG. The factor which yields wide range is the most significant one. The ranks are based on average GRG.





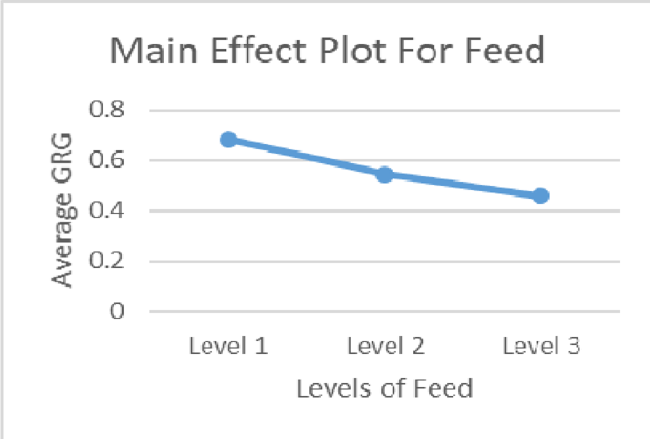


Figure 5: Main Effect Plot for Average GRG Vs Levels of Each Factor.

4.2 Selection of Optimum Levels of Process Parameters

The optimum setting is one for which the average GRG for a given factor is maximum

The optimum setting is A_1-B_1- C_1i.e Drill diameter 6 mm –Speed 750RPM and Feed 50 m/min.

4.3 Application of ANOVA for Finding the Significance of Each Factor

In order to reconfirm optimum setting, ANOVA is performed and the Sum of squares for each level is listed in Table 6.

Table 6: The Total GRG with Corresponding Factors

Factors	A	B	C
Level 1	6.20268659	5.220731844	6.141705055
Level 2	5.12083368	5.081851512	4.911038258
Level 3	3.825276407	4.86506946	4.114909503
Sum of squares SS factors	0.293677865	0.007139924	0.231713406
Sum of squares Error SS error	0.054026		

Based on the above calculations, the un-pooled ANOVA on GRG is calculated. The values are shown in Table 7.

Table 7: Estimated ANOVA on GRG

Factors	Sum of Squares	Degrees of Freedom (DOF)	Mean Sum of Squares (MSS)	F Calculated	F Table (5% risk)	Remark	Percentage Contribution	Rank
A	0.293	2	0.086	29.54	3.49	Significance	61.60	1
B	0.007	2	5.1E-05	0.017	3.49	Not Significance	0.03	3
C	0.231	2	0.053	18.39	3.49	Significance	38.35	2
Error	0.054025667	20	0.002					
Total	**0.586556862**	**26**						

The factor for which F calculated > F table is the significant factor. In addition, percentage contribution for each factor is calculated by dividing each value of F calculated by Total of F calculated. The values of percentage contribution shows that the ranks for each factor given in table 4 are confirmed.

4.4 Calculation of Predicted GRG

The predicted GRG is calculated using the following formula

Let T = Overall average of Gray Relational Grades = Total GRG/27 =0.561

The predicted GRG is given by $GRG_{predicted} = Average\ GRG\ for(A_1 + B_1 + C_1) - 2T$

The predicted GRG is given by $GRG_{predicted}$ =0.828

4.5 Calculation of Confidence Interval C.I.

The confidence interval indicates the expected range of GRG for the optimal settings. The calculation for confidence interval is shown below.

Half width of confidence interval d = $\sqrt{\frac{F_{\alpha(1,dof\ of\ error)} * MSS_{error}}{\eta_{eff}}}$ where η_{eff} is the effective sample size.

The effective sample size $\eta_{eff} = \frac{N}{(1 + Total\ of\ Dof\ of\ each\ factor)} = \frac{27}{7}$= 3.85

The $F_{\alpha(1,Dof\ of\ error)}$ $is\ taken\ from\ F\ table\ .\ \alpha = 95\%$ (confidence level), DOF of error is 16.

d = $\sqrt{\frac{8.61*0.0029}{3.85}}$ =0.034

The confidence interval of predicted mean for 95% confidence level (C.I) is given by,

C.I. = Predicted average GRG $\pm d$;0.793768825<C.I.<0.862532273

The confirmation test was conducted for the optimal setting as follows

Drill angle 118^0, Drill Diameter 06 mm, Speed 750 RPM and Feed 50 mm/min.

The GRG calculated for this setting was 0.712 which is well within the range of Confidence interval. So optimal setting is confirmed.

The input parameters are independent of each other and the effect of each parameter on responses is difficult to evaluate. The output responses i.e. minimum values of drill diameter, speed and feed ensure optimum setting because minimum diameter results in less torque which in turn reduces delamination due to less force of separation. Less speed leads to less torque, good surface finish. Also, less feed produces less thrust. The combination of these three parameters gives optimum setting as shown by Gray Relational Analysis.

5. CONCLUSIONS

- Gray Relational Analysis is a simple and effective tool in optimizing process parameters when the variables are independent and influence of each process parameter on individual response is not known.
- The Taguchi method ensures minimum number of trials to be conducted with minimum error in the prediction.
- The drill diameter is the most significant factor followed by feed and speed.
- The results obtained by GRG are complimented by ANOVA which shows high Confidence interval (0.79 to 0.86)
- The Confirmation test indicates the reliability of the predictions of GRG. In this paper the GRG with optimum setting is within the confidence interval depicting proper optimal setting.

- Since the objective is to minimization of the value of all output variables, the optimum results is obtained by setting minimum values for input variables.

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